———, AND H. K. KAYA. 1990. Water potential, temperature, and clay-coating on survival of *Beauveria bassiana* conidia: Effect on *Spodoptera exigua* pupal mortality in two soil types. J. Invertebr. Pathol. 56: 327-336.

VILLANI, M. G., AND R. J. WRIGHT. 1990. Environmental influences on soil macroarthropod behavior in agricultural systems. Ann. Rev. Entomol. 35: 249-269.

WALLACE, H. R. 1971. Abiotic influences in the soil environment, pp. 257-280 *in* B. M. Zuckerman, W. F. Mai, & R. A. Rohde [eds.], Plant parasitic nematodes, Vol. 1. Academic, New York.

WALSTAD, J. D., R. F. ANDERSON, AND W. J. STAMBAUGH. 1970. Effects of environmental conditions on two species of muscardine fungi (*Beauveria bassiana* and *Metarrhizium anisopliae*). J. Invertebr. Pathol. 16: 221-226.

WOOD, M. 1989. Soil biology. Chapman & Hall, New York.

WOMERSLEY, C. Z. 1990. Dehydration survival and anhydrobiotic potential , pp. 117-137 *in* R. Gaugler & H. K. Kaya [eds.], Entomopathogenic nematodes in biological control. CRC Press, Boca Raton.

BIOLOGICAL CONTROL OF WEEVILS AND WHITEGRUBS ON BANANAS AND SUGARCANE IN THE CARIBBEAN

C. SIRJUSINGH,[1] A. KERMARREC,[2] H. MAULEON,[2] C. LAVIS[2] AND J. ETIENNE[2]

[1]University of the West Indies
Department of Zoology
St. Augustine, Trinidad

[2]INRA
Station de Zoologie et Lutte Biologique
97185, B.P. 1232, Pointe-à-Pitre
Guadeloupe, FWI

ABSTRACT

This review examines the major weevil and whitegrub pests on bananas and sugarcane of present economic concern in the Caribbean, as well as the various categories of biocontrol agents. It discusses their roles in reducing populations of these pest. Several successful biocontrol agents are presented together with recently obtained information that may affect practical biocontrol. Some directions of future research in this field are predicted. Emphasis will be made on *Cosmopolites sordidus* on banana and *Diaprepes abbreviatus* on sugarcane, targets of the main biological control attempts.

RESUMEN

Se revisan las mayores plagas coleopteras del suelo en banano y cana de azucar. Estas plagas representan un problema de tipo economico, y se consideran aqui varias categorias de control biologico. Se discute su importancia en la reduccion de las poblaciones de estas plagas. Se presenta informacion reciente la cual puede afectar el uso practico de varios agentes de control biologico. Se dan sugerencias y predicciones sobre la futura investigacion en esta area. El mayor enfasis de la investigacion en control biologico debe ser en las plagas mas importantes, *Cosmopolites sordidus* en banano y *Diaprepes abbreviatus* en caña de azucar.

Banana and sugarcane are traditional cash crops in the Caribbean and generate substantial foreign revenue from their export. The increasing pressure felt by developing countries to expand local production has forced adoption of plant production technologies from industrialized countries, such as intensive chemical control. Unfortunately, the short term benefits derived from the increased use of pesticides are given priority over the long term benefits of alternative methods of plant protection. The negative effects of pesticides are well documented and include induced resistance, emergence of secondary pests, reduced populations of beneficial insects, as well as increased human and environmental health hazards. With the increasing costs of developing new pesticides, countries are researching alternatives to chemicals. Future crop protection in the tropics must now concentrate on biological control.

Weevils and whitegrub pests of sugarcane and bananas (Table 1) are well known to cause extensive damages in the Caribbean. Many weevils and grubs, although maintained at economically acceptable levels by chemicals in some regions, have populations levels which cause serious damage (Gruner 1975, Alam et al. 1991). Several review articles with extensive literature citations published during the past three to four decades demonstrate the dramatic increase of research efforts, and awareness of the impor-

TABLE 1. WEEVIL AND WHITEGRUB PESTS OF BANANAS AND SUGARCANE IN THE CARIBBEAN.

Pest	Country
SUGARCANE	
Major Pests	
Curculionidae	
Anacentrinus insularis	Cuba
Diaprepes abbreviatus	Antilles (except Jamaica), Florida, Puerto Rico
Dyscinetus picipis	Cuba
Metamasius sericeus	Cuba
Metamasius sp.	Puerto Rico
Scarabaeidae	
Ligyrus subtropicus	Florida
Phyllophaga smithi	Barbados
Phyllophaga portoricensis	Puerto Rico
Minor Pests	
Scarabaeidae	
Anomala sp.	French Antilles, Florida
Cyclocephala spp.	French Antilles
Cyclocephala parallela	Florida
Ligyrus cuniculus	French Antilles
Phyllophaga patrueloides	French Antilles
BANANAS	
Major Pests	
Curculionidae	
Cosmopolites sordidus	Pantropical
Minor Pests	
Curculionidae	
Metamasius hemipterus	Antilles
Scarabaeidae	
Phyllopaga pleei	French Antilles

TABLE 2. NATURAL ENEMIES OF *COSMOPOLITES SORDIDUS* AND THEIR BIOLOGICAL CONTROL POTENTIAL IN THE CARIBBEAN. (NA-NOT YET ASSESSED)

Natural Enemies		Country	Potential
FUNGI (Delattre & Jean-Bart 1978, Castiñeiras et al. 1990)			
Beauveria bassiana and *Metarhizium anisopliae*		French Antilles and Florida, Cuba, Brazil	Very Good
HELMINTHS			
Entomopathogenic Nematodes (Kermarrec & Mauléon 1975, Peña & Duncan 1990, Sirjusingh et al. 1990, Figueroa & Roman 1990)			
Heterorhabditis sp.		Guadeloupe, Florida	Good
H. bacteriophora		Guadeloupe, Florida	Results variable
H. heliothidis		Guadeloupe, Florida	Results variable
Steinernema bibionis		Guadeloupe, Florida, P. Rico	None
S. feltiae (=*S. carpocapsae*)		Guadeloupe, Florida, P. Rico	Good
S. glaseri		Guadeloupe, Florida, P. Rico	None
Plathyhelminths (Becarri 1967)			
Turbellaria	*Geoplana coerulea*	Brazil	NA
INSECTS			
Coleoptera (Neuenschwander 1988, Becarri 1967, Peña & Duncan 1990)			
Carabidae	*Propagalorita bicolor*	Florida	NA
	Scarites sp.	Florida	NA
Histeridae	*Plæsius javanus*	Trinidad, Jamaica, Cuba	Not established
	Hyposolenus lævigatus	Trinidad	NA
	Hololepta quadridentata	Trinidad	Established
	Hololepta spp.	St. Vincent	NA
	Lioderma sp.	Brazil	NA
	Platysoma abruptum	Brazil	NA
Hydrophilidae	*Dactylosternum hydrophiloides*	Trinidad	NA
	D. abdominalis	Trinidad	NA
	D. profundum	Trinidad	NA
	D. intermedium	Trinidad	NA
	Omicrogiton insularis	Brazil	NA

Silvanidae	*Cathartus* sp.	Brazil	Not established
Staphylinidae	*Belonuchius ferrugatus*	Brazil	Not established
	B. quadratus	Brazil	NA
	Leptochirus unicolor	Brazil	Not established
Dermaptera			
Labidurldae	*Annisolabis annulipes*	Brazil	NA
	Psalis americanum	Brazil	NA
Diptera			
Rhagionidæ	*Chrysopilus* sp.	Brazil	Not established
Hemiptera			
Cydnidae	*Geotomus pygmaeus*	Brazil	NA
Miridae	*Fulvius nigricornis*	Brazil	NA
Nabidae	*Phorticus pygmaeus*	Brazil	NA
Reduvidae	*Physoderes curculionis*	Brazil	NA
Hymenoptera			
Formicidae	*Pheidole megacephala*	Cuba	Good (Castiñeiras et al. 1990)
	Tetramorium guineense	Cuba	Very Good (Roche & Abreu 1983)
VERTEBRATES			
Amphibia	*Bufo marinus*	S. America	NA (Becarri 1967)

tance of biological control of insect pests (Neuenschwander 1988, Alam et al. 1991, Rajabalee 1991, Peña 1991). Several of the early attempts at biological control of these pests failed due to the inadequacy of an information resource base. However, present knowledge on the natural enemies of weevil and whitegrub pests provides valuable information on potential of biocontrol agents in the fields.

BIOLOGICAL CONTROL OF BANANA PESTS

Cosmopolites sordidus (Coleoptera: Curculionidae)

Banana and plantain in the tropical and subtropical regions have been adversely affected by infestations of *Cosmopolites sordidus*. Serious outbreaks have been reported in the last five years in Africa, Australia, Brazil, the Caribbean and S.E. Asia (Arleu & Neto 1984, Prasad & Singh 1987, Neuenschwander 1988). There have also been reports of resistance to the organochlorines (aldrin and dieldrin) which initially offered good control (Wright 1977). Research on the natural enemies of this pest has generated an inventory of natural parasitoids, parasites, predators and pathogens collected from all over the world (Table 2). However, the importance of many of the predators as biocontrol agents remains uncertain and warrants future study. Several early introductions of insects predators such as *Plaesius javanus* (Histeridae) from Fiji, *Dactylosternum hydrofiloides* and *D. abdominalis* (Hydrophilidae) from Malasia into Cuba and Jamaica did not become established (Neuenschwander 1988). Many of these initial introductions were unsuccessful because they were generalist predators, poorly studied before being introduced, and often failed to become acclimatized.

The predaceous ants, *Pheidole megacephala* and *Tetramorium guineense*, are reported to give good levels of control of this pest in Cuba (Castiñeiras et al. 1991, Roche & Abreu 1983). Treatments of nine colonies of *P. megacephala* per hectare (Castiñeiras et al. 1991), resulted in a 55% reduction of the *C. sordidus* population, 65% reduction in banana corn damage and an overall 25% increase in crop yield. This result was comparable to the control achieved by chemical control (59-64%). The high capacity of *T. guineense* for *C. sordidus* larvae as prey results in rapid colonization of banana fields with 83% mortality of larvae in low infestations and 67% in highly infested fields (Roche & Abreu 1983). In Guadeloupe (Jaffé et al. 1990), several species of predaceous ants, such as *Azteca antillana*, which are highly territorial have a negative association with other ant species, and apparently preventing other effective ant species, such as *Tetramoriurm* spp., from becoming established in banana fields. However, several generalist predator species, such as *Azteca* spp., *Solenopsis geminata*, *Wasmannia auropunctata* and *Pheidole fallax* (Table 3), are present and may already be contributing to some natural control of *C. sordidus* in Guadeloupe.

Local and exotic strains of entomopathogenic nematodes of the Heterorhabditidae and Steinernematidae have been tried against *C. sordidus* adults and larvae (Figueroa 1990, Kermarrec & Mauleon 1975, Peña & Duncan 1991, Sirjusingh et al. 1991). These nematodes are very effective against the larval stages but less effective against the adults, which unfortunately are the soil target (Fig. 1). Kermarrec and Mauléon (1975) demonstrated a significant positive relationship between the dose of *Steinernema carpocapsae* (Agriotos strain) applied and mortality of the adult weevil (Fig. 2). Figueroa (1990) obtained up to 50% mortality of 6-7th instar larvae in infected corms using *S. carpocapsae*, *S. bibionis* and *S. glaseri*. Other trials using these nematodes have produced inconsistent results. Peña & Duncan (1991) reported wide fluctuations in larval mortality (45-89%) using the nematodes. However, more recently Peña (1991, unpublished) has reported a mortality level of up to 80% of *C. sordidus* larvae in banana corms by a strain of *Heterorhabditis* sp. from Florida. From over 17 strains of entomopathogenic nematodes bioassayed against *C. sordidus* adults and larvae, *Heterorhabditis* sp. (HT2-Trinidad strain) and the commercial strain of *S. carpocapsae* (All-Biosafe®) (Sirjusingh et al. 1991) gave the most promising results against both adults and larvae (Fig. 1). Combination of these two strains with a 10^{-2} dilution of the insecticide, aldicarb (Temik®) produced results (Fig. 3) with up to 100% adult mortality in 8 days compared with 60% using aldicarb, 35% and 50% using HT2 or All alone, respectively. Similar results were found by Kermarrec & Mauléon (1989) using *S. carpocapsae* (Agriotos strain) combined with a reduced concentration of chlordecone (Fig. 4), reported more effective mortality of adult weevils than with other treatments. However, chlordecone is now prohibited from use in several countries. Nevertheless, these experiments have been valuable for illustrating the compatibility between entomopathogenic nematodes and pesticides for control of the banana weevil borer. Sikora (pers. communication, 1990), suggests on the base of a work in Tonga, that the pathogenicity of one nematode strain may vary because of the existence of different levels of susceptibility or resistance of geographically different populations of *C. sordidus*. This interesting point of view is yet to be verified, but stresses the importance of preliminary screening of the nematodes against the specific *C. sordidus* populations before field trials. Kermarrec & Mauléon (1975) have shown that (Fig. 5) nematode parasitism of the weevil is attained primarily via the buccal cavity, through the digestive tract, and into the hemocoel where they can successfully resume their development from infective to parasitic stages. When the rostrum of the weevil is experimentally obstructed the nematodes can still penetrate the weevil to reach the hemocoel. The alternative modes of entry may be the spiracles, body articulations or anus. This experiment shows that weevil morphology directly influences it's affinity to be parasitized by the nematode. This affinity would be expected to vary among different biotypes of *C. sordidus* populations due to their possible inherent morphological differences.

At present, the most promising biological control agents tested are the classical entomopathogenic fungi (Fungi imperfecti) *Beauveria bassiana* and *Metarhizium anisopliae* against the larvae and adults of *C. sordidus*. In Cuba, (Castiñeiras et al. 1991) 17 strains of *B. bassiana* and 11 strains of *M. anisopliae* were screened against *C. sordidus*. The best results (61% and 85% mortality) were obtained from a dose of 10^5 conidiospores per cm^2 of soil with local strains of *B. bassiana* and *M. anisopliae*, respectively. In Brazil, Batista Filho et al. (1989) obtained mortality rates of 85% and 97% of *C. sordidus* using cultures of *B. bassiana* and *M. anisopliae* prepared on soaked rice or beans, by allowing the insects to walk on the fungal cultures, or by directly treating banana pseudostem pieces so that the weevils became infected during colonization. In Cuba, Calderón et al. (1991) have achieved efficient and economical mass-production of various strains of these two fungi species against *C. sordidus* using bagasse or other agro-industrial by-products. Two virulent strains of *B. bassiana* (Bb32) and *M. anisopliae* (Bio-1020), entomopathogenic for *C. sordidus* and *Metamasius hemipterus*, are now being used in field trials in Martinique by the authors. The pathogenicity of strains, isolated from parasitized coleopteran larvae in Guadeloupe, have been compared with exotic strains of these fungi (Delattre & Jean-Bart 1978). The latter also reported that, in general, higher levels of mortality were achieved by local strains of *B. bassiana* isolated from *C. sordidus* than exotic strains from the Colorado potato beetle, *Leptinotarsa decemlineata*. However, imported strains may also show equal pathogenicity to *C. sordidus*. In preliminary field experiments (op. cit.), the disease rarely developed in the treated population. Nevertheless, adult weevils collected from one treated site and observed in laboratory developed symptoms of *B. bassiana* mycosis after one month, resulting in up to 80% mortality. This suggests that inhibitory mechanisms may be operating in the weevil population, resulting in a latent manifestation of the disease. In Taiwan (Yu-Chen 1964), spores suspensions of *M. anisopliae*

TABLE 3. NATURAL ENEMIES OF *DIAPREPES ABBREVIATUS* AND THEIR BIOLOGICAL CONTROL POTENTIAL IN THE CARIBBEAN (NA-NOT YET ASSESSED).

Natural Enemies	Country	Potential Control
FUNGI (Beavers et al. 1983, Cruz & Segarra 1990, Mauléon et al. 1987)		
Beauveria bassiana (A,La)	Antilles, Florida, P. Rico	Good
Cordiceps sp. (La)	French Antilles	Some
Fusarium (La)	P. Rico	Very good
Geotrichum (La)	P. Rico	42% mortality
Gliocladium (La)	P. Rico	Very good
Gongronella (La)	P. Rico	17% mortality
Metarhizium anisopliae (A,LA)	P. Rico, French Antilles	Good
Mucor (La)	P. Rico	42% mortality
Nomuraea rileyi (La)	French Antilles	Some
Paecilomyces lilancinus (La)	Florida	Some
P. fumoso-roseus (La)	French Antilles	Some
ENTOMOPATHOGENIC NEMATODES (Alam et al. 1990, Bonifassi et al. 1988, Schroëder 1987)		
Heterorhabditis sp. (Guadeloupe strain)	Guadeloupe	Very good
Heterorhabditis bacteriophora (La)	French Antilles	Good
Heterorhabditis heliothidis (La)	Florida, P. Rico	Good
Steinernema bibionis (La)	P. Rico	Good
Steinernema carpocapsae (La)	Florida, P. Rico, Barbados	Good
Steinernemaglaseri (La)	P. Rico	Very good
INSECTS HYMENOPTERA		
Predator Ants (Alam, pers comm., Cruz & Segarra 1990, Jaffé et al. 1990)		
Azteca delpini (All stages)	French Antilles	Good but aboreal
Azteca antillana (A)	French Antilles	Very good
Brachymyrmex obscurior (La)	Puerto Rico, Barbados	Good
Camponotus spp. (A,La)	French Antilles, Barbados	Good, terrestrial
Cardiocondyla emeryi (La)	P. Rico	Some
Conomyrma insana (La)	P. Rico	Some
Crematogaster sp. (La, egg)	French Antilles	Good but aboreal
Ectatomma ruidum (La, egg)	French Antilles	Good, terrestrial

Monomorium floricola, M. destructor (Egg)		French Antilles	Good but aboreal
Odontomachus brunneus (La)		P. Rico	Good
Parathrechina longicornis (La, egg)		French Antilles, Barbados	Good, terrestrial
P. bourbonica (A,La)		Florida	Good (Whitcomb et al. 1982)
Pheidole fallax (All stages)		P. Rico, French Antilles, Barbados	Very good
P. subarmata borinquensis (La)		P. Rico	Very good
Solenopsis geminata (A,La)		P. Rico, Barbados	Very good, terrestrial
Tetramorium simillimum (A,La)		Florida	Good (Whitcomb et al. 1982)
Tapinoma littorale (La)		French Antilles	Good, terrestrial
Wasmannia auropunctata (La)		Antilles	Good, terrestrial
Egg Parasites (Fennah 1947, Etienne et al. 1990a, 1990b)			
Eulopidae	*Aprostocetus* sp.	Guadeloupe	Good
	Aprostocetus gala	Jamaica, Guadeloupe, Cuba	Good
	A. haitiensis	Guadeloupe, Florida	
		Dominican Rep., Haiti	Good
	Eutetrastichus fennahi	Barbados, St. Lucia,	
		Dominica, Jamaica, Martinique	NA
	Pediobius irregularis	Honduras	NA
Mymaridae	*Cleruchus* sp.	Florida	NA
Plastygastridae	*Fidiobia citri*	Jamaica, Florida, Martinique	Good
Tachinidae	*Cenosoma* spp.	Cuba	Good
Trichogrammatidae	*Brachyufens osborni*	Cuba, Florida, Monsterrat, P. Rico	Good
	Ceratogramma etiennei	Guadeloupe	Good
	Trichogramma n. sp.	Florida	NA
VERTEBRATES (Mauléon et al. 1987)			
Amphibia	*Bufo marinus*	Guadeloupe, Barbados	Some
Reptilla	*Anolis marmoratus*	Guadeloupe	NA
Aves	*Quiscalus lugubris*	Guadeloupe	NA
Mammalia	*Herpestes favanicus auropunctatus*	Guadeloupe	NA

injected directly into the pseudostem of the banana plant were more effective against larvae than adults of the banana weevil *Odoiporus longicollis* (with a very similar life-cycle to *C. sordidus*). Peña (pers. comm.) stresses the technical difficulty of the injection and also the migration of the fungal inoculum injected into the pseudostem.

Metamasius hemipterus sericeus (Coleoptera: Curculionidae)

Population resurgences of *M. hemipterus* are often recorded in the West Indies both on banana and sugarcane (Delattre & Jean-Bart 1977). Because of their high mobility and ability to detect food and substrates, together with a patchy distribution. Therefore it is difficult to detect, monitor the size, follow the population growth, and estimate the damages caused by this weevil. Trials with the tachinid, *Microceromasia sphenophori* failed (Simmonds 1969, *in* op. cit.). *Metarhizium anisopliae* seems to offer active control in nature (Delattre & Jean-Bart 1977). The latter have reported that *M. hemipterus* larvae are highly sensitive to *B. bassiana* and *M. anisopliae*, but so far trials have not been very conclusive due to high mortality recorded in the control. In Cuba, where this weevil is important on sugarcane (Estrada 1991), Diaz Sanchez & Grillo Ravelo (1986) have isolated a strain of *B. bassiana* from the sweet potato weevil, *Cylas formicarius elegantulus* (Curculionidae) which is reported to be highly pathogenic to *C. sordidus* and *M. hemipterus sericeus*.

Biological Control of Sugarcane Pests

Diaprepes abbreviatus (Coleoptera: Curculionidae)

Diaprepes abbreviatus is a major weevil pest in Florida, Puerto Rico, and the West Indies (Beavers et al. 1983, Figueroa & Román 1990), and has been the target of numerous biological control attempts (Table 3) due in part to the fact that there are no chemicals with an EPA use permit available for larval control of this pest (op cit.). During the 1975 decade, hymenopterous egg parasites, *Aprostocetus* (=*Tetrastichus*) sp., *A. gala* and *A. haitiensis* (Jamaica, St.Vincent and Monsterrat), *Brachyufens osborni* (Florida) and *Fidiobia citri* (Jamaica) were introduced into Barbados (op. cit.). These parasites did not attack eggs on sugarcane. Cruz & Segarra (1991) suggest that they do not become significantly established on this crop due to the difficulty in parasitizing eggs of *D. abbreviatus* through the sugarcane leaves. However, the extent to which these organisms can be efficient on sugarcane is not clear and warrants further investigation.

In the French West Indies (Guadeloupe and Martinique) the egg parasites of *D. abbreviatus* have been studied (Etienne et al. 1991): 6 hymenopteran species have been found (Eulophidae: *Aprostocetus gala*, *A. haitiensis*, *Aprostocetus* sp. and *Eutetrastichus fennahi*. Trichogrammatidae: *Ceratogramma etiennei*, Platygastridae: *Fidiobia citri*). The biology and the dynamics of the new species of Trichogrammatidae, *C. etiennei*, have been studied (Etienne et al. 1991) for its use in integrated control programs against. *D. abbreviatus* in the Caribbean.

Ants (Table 3) are the most common predators of *D. abbreviatus* in Martinique and Guadelopue (Jaffé et al. 1991) with *Pheidole fallax* as the most effective. These authors have proposed for the French Antilles, the use of *Azteca antillana* alone (because they exclude all other species from the zone they inhabit), or a combination of *P. fallax* and/or *Solenopsis geminata* in the soil plus *Monomorium* sp. (egg predator) and/or *Tetramorium* sp. on the trees. In Puerto Rico, (Cruz & Segarra 1991) *P. fallax* and *P. subarmata borinquensis* already offer effective control. The difficulty with ants as biological control agents is that many are generalist predators and aggressive competitors. There is significant interspecific competition. In addition, some species, such

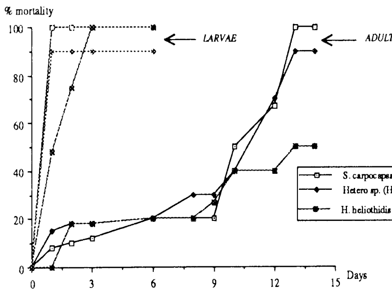

Fig. 1

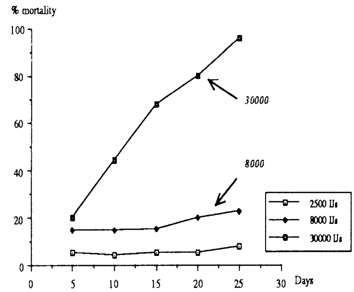

Fig. 2

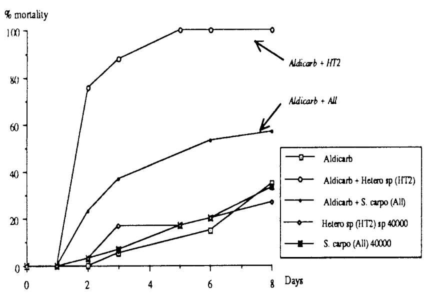

Fig. 3

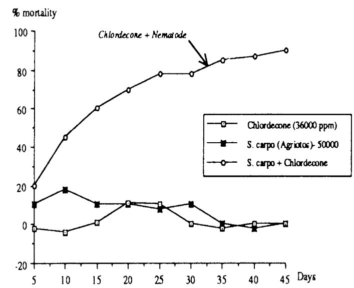

Fig. 4

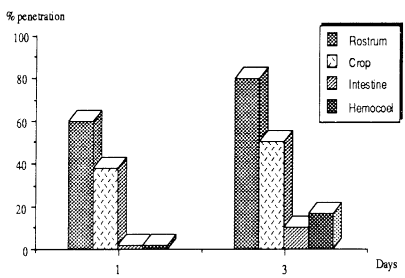

Fig. 5

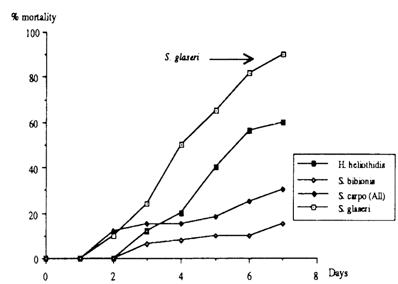

Fig. 6

* All graphs show Abbott Mortality: (Treated - Control /100 - Control) x 100

Fig. 1. Susceptibility of *C. sordidus* adults and larvae to nematodes (1000 IJs/larva, 4000 IJs/adult, on wetted blotting paper in Petri dishes, 10 targets per dish, 10 replicates).

Fig. 2. Effect of nematode dose (*S. carpocapsae* - Agriotos) on mortality of *Cosmopolites sordidus* adults (see legend of Fig. 1).

Fig. 3. Synergy between nematodes (IJs) and Aldicarb at 400 ppm (Sirjusingh et al. 1990).

Fig. 4. Synergy between nematodes (50000 IJs) and Chlordecone (36000 ppm) (Kermarrec & Mauléon 1989).

Fig. 5. Penetration of *C. sordidus* adults by *Steinernema carpocapsae* (Agriotos) (20000 IJs/adult, see legend Fig. 1).

Fig. 6. Effect of nematodes on larvae of *Phyllophaga pleei* (200 LJs/larva, see legend Fig. 1).

as *Solenopsis geminata* and *Wasmannia auropunctata*, have severe stings, and *W. auropunctata* also readily invades human habitats. Because of these reasons, manipulation of ant colonies for biological control is not easy and often not feasible when there are a wide variety of species. However, they should be regarded as an important part of the natural enemy complex or predaceous community of the sugarcane agroecosystem.

Entomopathogenic fungi and nematodes have also been tested for control of *D. abbreviatus* on sugarcane. Of the numerous strains (Table 2), *M. anisopliae* and *B. bassiana* are consider promising because of their superior pathogenicity and effectiveness for controlling both adults and larvae. In Puerto Rico, Cruz & Segarra (1991) reported that fungi of the genera *Gliocladium*, *Gongronella*, and *Fusarium* are the most pathogenic, resulting in significant control of the weevil under field conditions. The feasibility and efficacy of these strains of potential plant pathogenic fungi as invertebrate biocontrol agents need to be ascertained.

In laboratory bioassays, Schroëder (1987) achieved 35% and 65% mortality of *D. abbreviatus* larvae with *Steinernema carpocapse* and *S. glaseri*, respectively. Alam et al. (1990) indicates that *S. glaseri* is slowly becoming established in Barbados on sugarcane with 21% to 33% incidence of the nematode in treated fields from 1984 to 1987. Figueroa and Román (1990) reported the effectivity of *S. bibionis*, *S. carpocapsae*, and *S. glaseri* on 12-14 weeks old larvae of *D. abbreviatus* in potted soil treatments. Bonifassi et al. (1988) compared in greenhouse studies, different application techniques for *Heterorhabditis* sp. (Guadeloupe strain), *S. bibionis* and *S. glaseri*, and showed that the former species was the most pathogenic to *D. abbreviatus* (94% mortality) when applied directly to the soil suspended in water.

Phyllophaga spp. (Coleoptera: Scarabaeidae)

Phyllophaga smithi is a serious pest of sugarcane in the Eastern Caribbean (Alam et al. 1991). In Barbados there have been several introductions of natural enemies for *P. smithi*. The beetle, *Pyrophorus luminosus*, and the toad, *Bufo marinus*, were established according to the latter authors. They also reported the slow field establishment of *S. glaseri*, with almost 13% and 17% control achieved in 1984 and 1987, respectively. *Phyllophaga smithi* was accidentally introduced into Mauritius from Barbados in 1907, attained major pest status by 1935 (Rajablee 1991). An unexplained rapid decline in the population of this whitegrub has been recently observed. Investigations have shown that over 95% of all *P. smithi* larvae collected in Mauritius are infected by an undescribed eucephaline gregarine in the anterior coelom (op. cit.). Vercambre et al. (1991) reports that this organism retards the growth of young larvae, reduces the fecundity of females, and weakens all stages, making them more susceptible to other diseases. The result is that almost half of the whitegrub population fails to complete their life cycle. Insufficient knowledge of the biology of these protozoans prevents their integration into biological control programs. The latter authors have reported that inoculation of this organism into populations of the melolonthid, *Hoplochelus marginalis*, on sugarcane in Reunion, has failed due to the specificity of the protozoan to *P. smithi*. However, the potential of this protozoan for control of *P. smithi* in the Caribbean needs to be assessed.

In the Antilles, larvae of various *Phyllophaga* spp. are occasionally found at sufficient levels to be considered important secondary pests of banana and sugarcane plantations. *Phyllophaga portoricensis* (sugarcane) in Puerto Rico, *P. pleei* (borders of banana plantations) and *P. patrueloides* (sugarcane) in the French Antilles, have been the targets for entomopathogens (Wolcott 1955, Gruner 1973). The latter reports that these whitegrubs appear to be very resistant to *Metarhizium anisopliae* (7 strains) with the most virulent strains having been isolated from the same insect. Very high doses are required for good results (up to 10^7 spores per gram of peat). Reduced doses of insecticides combined with fungal spores resulted in a higher mortality, but not a better development of the mycosis. However (op. cit.), forced ingestion of *Bacillus popilliae* one month before cryptogamic treatment renders the insect more susceptible to the disease. The same is true for intrahemocoelic injection of the virus, *Vagoiavirus melolonthae* (strain 'Melolontha') 40 days after applying spores of *M. anisopliae* to the substratum. In the field the larvae develop *B. popilliae* bacteriosis and *M. anisopliae* mycosis simultaneously. This synergy between fungi and bacteria or viruses is promising and presents interesting possibilities for the control of *Phyllophaga* spp.

Kermarrec & Mauléon (1975) found that the entomopathogenic nematode *S. carpocapsae* (Agriotos strain) did not penetrate adults or larvae of *P. pleei*. From a more recent study (Mauléon & Tormin 1990), *S. glaseri* produced the best results (of up to 90% larval mortality within 7 days) from the 15 strains of heterorhabditids and steinernematids tested (Fig. 6).

Ligyrus subtropicus (Coleoptera: Scarabaeidae)

Ligyrus subtropicus is the most destructive whitegrub to sugarcane production in Florida with no widespread practical method of control available. Five species of entomopathogenic nematodes have been tried against this pest (Sosa & Beavers 1985, Sosa 1990). *Steinernema glaseri* seems to be the most promising nematode, resulting in up to 100% mortality in laboratory bioassays and up to 50% whitegrub infection in treated plots. The advantage of using these nematodes on sugarcane in Florida is that the target would be major whitegrub pest complex consisting of *L. subtropicus* as the most important together with *Cyclocephala parallela* and *Anomala* sp. as secondary whitegrub pests, all of which are susceptible to entomopathogenic nematodes (Laumond et al. 1979). Potential entomopathogenous micro-organisms are *Bacillus popilliae*, *Metarhiziurn anisopliae* var. *major*, *Beauveria bassiana* and *Verticillium lecontei*, which were isolated from third instar *C. parallela* and *L. subtropicus* grubs in Florida (Boucias et al. 1986). *B. popilliae* was the most prevalent pathogen in these whitegrub populations in Florida sugarcane fields with an incidence of over 90% of all fields sampled (op. cit.).

Conclusions and Future Research Proposals

Assessments of the outcome of many previous biological control attempts in the Caribbean are poorly documented. Extensive programs and control methods for weevils and whitegrubs have been elaborated upon but their implementation remains unsatisfactory. It is necessary to standardize the scientific methodologies applied in biological control, as well as to design universally accepted protocols and techniques recognized by international research world, so as to generate more comparative results from biocontrol attempts. The application and management of biocontrol agents should be developed case by case, taking into consideration the prevailing socioeconomical, cultural, and environmental conditions.

Some areas of immediate investigation, which may be potentially beneficial are (1) to assess the approach of direct inoculation of entomopathogenic fungi into the pseudostem of the banana plant against *C. sordidus* larvae according to Yu-Chen (1964); (2) to exploit the effectiveness of hymenopteran egg parasites of *D. abbreviatus* (Etienne et al. 1991) for sugarcane, and (3) to elucidate the pathogenicity of the maurician eucephaline protozoan (Rajabalee 1991) on *Phyllophaga* populations and it's potential for application in the Caribbean. Another important area of further research concerns the entomopathogenic - nematodes and fungi, a common parameter linking the biological control of these particular weevils and whitegrubs. These biocontrol agents are generally cosmopolitan, with some exceptions, therefore the universal applicability is an inherent advantage. But the interactions between these entomopathogens and the insect pests are complex. The soil, although the principal natural reservoir of entomopathogenic nematodes and fungi, represents numerous constraints to their successful establishment and regulating activity. Soil type, soil particle size, pF (soil moisture potential) and temperature (Hominick 1991), mineral, organic and microbial composition (Riba et al. 1991) influence the persistence, biological activity, and epizootiological behavior of these entomopathogens. Lack of ecological knowledge is evident and understanding of the biological efficacy of these organisms and their role in controlling weevils and whitegrubs will remain academic until future studies provide us with information for their successful implementation as biocontrol candidates. Recent research emphasizing these aspects has been initiated with assessments of the soil environment on entomopathogenic fungi and nematodes (Hominick 1990, Mauléon et al. 1991, Riba et al. 1991). Continued research in this area is important as it is generally agreed that the elucidation of limiting abiotic and biotic factors will contribute significantly to more efficient use of entomopathogens.

References Cited

ALAM, M. M., J. REID, AND G. MULLER. 1991. The present status and future needs of biological control in the Caribbean community. Proc. of Caribbean Meetings on Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 49-61.

ARLEU, R. J., AND S. S. NETO. 1984. Broca de Bananeira *Cosmopolites sordidus* (Germar, 1824) (Coleoptera: Curculionidae). Turrialba 34(3): 359-367.

BATISTA FILHO, A., L. M. CAMARGO, I. MAYASKI, B. CRUZ, AND D. A. OLIVEIRA. 1989. Biological control of the banana root borer (*Cosmopolites sordidus*, Germar, 1824) by entomogenous fungi in the laboratory. Biologico 53(1-6): 1-6.

BEAVERS, J. B., C. W. MCCOY, AND D. T. KAPLAN. 1983. Natural enemies of subterranean *Diaprepes abbreviatus* (Coleoptera: Curculionidae) larvae in Florida. Environ. Entomol. 12: 840-843.

BECARRI, F. 1967. Contributo alla conoscenza del *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Revista di Agricultura Subtropicale e Tropicale, Firenze 61 (1/3): 51-93.

BONIFASSI, E., C. LAUMOND, F. MADEMBA-SY, AND H. MAULEON. 1988. Essai de contrôle de *Diaprepes abbreviatus* en pepinière à l'aide d'un nématode entomoparasite: *Heterorhabditis* sp. Coll. OILB. Versailles. 2-4 September.

BOUCIAS, D. G., R. H. CHERRY, AND D. L. ANDERSON. 1986. Incidence of *Bacillus popilliae* in *Ligyrus subtropicus* and *Cyclocephala parallela* (Coleoptera: Scarabaeidae) in Florida sugarcane fields. Environ. Entomol. 15: 703-705.

CALDERON, A., M. FRAGA, M. LUJAN, AND E. SANCHEZ. 1991. Reproduccion de *Beauveria bassiana* (Bals.) Vuill. y *Metarhizium anisopliae* (Metsch.) sobre subproductos industriales. Proc. of Caribbean Meetings on Biological Control. 5-7 Nov. Guadeloupe. F.W.I., pp. 325-326.

CASTINEIRAS, A., T. CABRERA, A. CALDERON, M. LOPEZ, AND M. LUJAN. 1991. Lucha biologica contra *Cosmopolites sordidus* (Germar). Proc. of Caribbean Meetings on Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 423-428.

CRUZ, C., AND A. SEGARRA. 1991. Recent biological control experiences in Puerto Rico. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 37-38.

DELATTRE, P., AND A. JEAN-BART. 1977. Modalites de declenchment des pullulations de *Metamasius hemipterus* (Coleoptera: Curculionidae). Facteurs limitatifs des populations. Nouv. Agron. Antilles-Guyane. 3(2): 55-65.

DELATTRE, P., AND A. JEAN-BART. 1978. Activités des champignons entomopathogènes (Fungi imperfecti) sur les adultes de *Cosmopolites sordidus* Germ. (Coleoptera: Curculionidae). Turrialba 28(4): 287-293.

DIAZ SANCHEZ, J., AND H. GRILLO RAVELO. 1986. An isolate of *Beauveria bassiana* Bals. (Vuill.) as a pathogen of *Cylas formicarius elegantulus* Summer. Centro Agricola 13: 94-95.

ESTRADA, E. M. 1991. Lucha biológica contra las principales plagas de la caña de azucar en Cuba. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe. F.W.I., pp. 17-24.

ETIENNE, J., G. DELVARE, AND H. MAULEON. 1990. The egg parasites of *Diaprepes abbreviatus* (Coleoptera: Curculionidae) in the French West Indies. Florida Entomol. Soc. Second Carib. Conf. of Entomol. August 6-9. Cancun, Mexico.

ETIENNE, J., H. MAULEON, AND P. PINTUREAU. 1991. Biologie et Dynamique de *Ceratogramma etiennei* (Hymenoptera: Trichogrammatidae) Parasite de *Diaprepes abbreviatus* (Coleoptera: Curculionidae) en Guadeloupe. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., 459-468.

FENNAH, R. G. 1947. *The insect pest of food crops in the Lesser Antilles.* Department of Agriculture. Windward and Leeward Islands. B.W.I. 207 pp.

FIGUEROA, W. 1990. Biocontrol of the banana root borer weevil, *Cosmopolites sordidus* (Germar), with Steinernematid nematodes. J. Agric. Univ. Puerto Rico. 74(1): 15-19.

FIGUEROA, W., AND J. ROMAN. 1990. Parasitism of entomophilic nematodes on the sugarcane rootstalk borer, *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae), larvae. J. Agric. Univ. Puerto Rico. 74(2): 197-202.

GRUNER, L. 1973. Sensibilisation des larves de *Phyllophaga pleei* Bl. et de *P. patrueloides* Pa. (Coléoptère: Scarabaeidae) à la mycose à *Metarhizium anisopliae* Sorokin au moyen d'une faible dose d'insecticide ou d'un autre agent infectieux. Annales de Zoologie et Ecologie Animale 5: 335-349.

GRUNER, L. 1975. Etude de l'activité des adultes de divers scarabeides antillais au moyen de piégages lumineux et chimiques. Annales de Zoologie et Ecologie Animale 7: 399-425.

HOMINICK, W. M. 1991. Ecological considerations for optimizing the effectiveness of entomopathogenic nematodes. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 205-214.

JAFFE, K., H. MAULEON, AND A. KERMARREC. 1991. Qualitative evaluation of ants as biological control agents with special reference to predators on *Diaprepes* spp. (Coleoptera: Curculionidae) on citrus groves in Martinique and Guadeloupe Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 405-416.

KERMARREC, A., AND H. MAULEON. 1975. Contrôle biologique expérimental de *Cosmopolites sordidus* par le Rhabditide *Neoaplectana carpocapsae* (Nematoda: Neoaplectanidae). 8th Congress de OTAN, St. Lucia, 4-5 August.

KERMARREC, A., AND H. MAULEON. 1989. Synergy between chlordecone and *Neoaplectana carpocapsae* Weiser (Nematoda: Steinernematidae) in the control of *Cosmopolites sordidus* (Coleoptera: Curculionidae). Rev. Nématol. 12: 324-325.

LAUMOND, C., H. MAULEON, A. KERMARREC. 1979. Données nouvelles sur le spectre d'hôtes et le parasitisme du nématode entomophage *Neoaplectana carpocapsae.* Entomophaga 24: 13-27.

MAULEON, H., AND P. TORMIN. 1990. Essai de lutte contre *Phyllophaga* spp. à l'aide de nématodes entomopathogènes en culture d'igname. INRA. Report unpublished.

MAULEON, H., B. P. BANH, AND A. KERMARREC. 1991. Influence de deux sols argileux tropicaux sur la survie et pouvoir pathogène des nématodes entomoparasites. Unpublished report.

MAULEON, H., J. ETIENNE, AND F. MADEMBA-SY. 1987. Lutte intégrée aux Antilles contre le charançon des agrumes: *Diaprepes abbreviatus.* ANPP, International conference on pests in agriculture: 441-445.

NEUENSCHWANDER, P. 1988. Prospects and proposals for biological control of *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) in Africa, *in* Nematodes and the borer weevil in bananas. Present status of research and outlook. Proc. of a workshop in Bujumbura, Burundi. 7-11 Dec. 1987.

PENA, J. E. 1991. Research proposal for control of *Cosmopolites sordidus* Germar. CBAG report, unpublished. 17 pp.

PENA, J. E., AND R. DUNCAN. 1991. Preliminary results on biological control of *Cosmopolites sordidus* in Florida. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 351-358.

PRASAD, B., AND O. L. SINGH. 1987. Insect pests of bananas and their incidence in Manipur. Indian Journal of Hillfarming 1: 71-73.

RAJABALEE, A. 1991. Etudes sur les vers blancs (Coleoptera: Scarabaeidae) de la canne à l'île Maurice. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 69-76.

RIBA, G., F. HAMDAOUI, B. VERCAMBRE, AND R. BOURNOVILLE. 1991. Ecologie des champignons entomopathogènes dans le sol. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 379-388.

ROCHE, R., AND S. ABREU. 1983. Control del picudo negro del plátano (*Cosmopolites sordidus*) por la hormiga *Tetramorium guineense*. Ciencas de la Agricultura 17: 49.

SCHROEDER, W. J. 1987. Laboratory bioassays and field trials of entomogenous nematodes for control of *Diaprepes abbreviatus* (Coleoptera: Curculionidae) in Citrus. Environ. Entomol. 16: 987-989.

SIKORA, R. A., AND P. F. PARNOTOZSKI. 1990. Intricacies involved in developing a biological control program for the banana weevil borer, *Cosmopolites sordidus*, using entomopathogenic nematodes in Tonga. Communication at the Caribbean Meetings in Biological Control. Guadeloupe. Unpublished.

SIMMONDS, N. 1966. *Bananas*. Trop. Agric. Series, London: Longmans. 512 pp.

SIRJUSINGH, C., H. MAULEON, AND A. KERMARREC. 1991. Compatibility and synergism between entomopathogenic nematodes and pesticides for control of *Cosmopolites sordidus* Germar. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 183-192.

SOSA, O. JR. 1990. Insect parasitic nematodes in sugarcane pest management. Comm. presented at Second Carib. Conf. of Entomol. August 6-9. Cancun, Mexico.

SOSA, O. JR., AND J. B. BEAVERS. 1985. Entomogenous nematodes as biological control organisms for *Ligyrus subtropicus* (Coleoptera: Scarabaeidae) in Sugarcane. Environ. Entomol. 14: 80-82.

VERCAMBRE, B., O. GOEBEL, O. MOREL, P. ROBERT, AND M. GUILLON. 1991. Programme de lutte biologique contre *Hoplochelus marginalis* (Coleoptera: Melolonthinae) nouveau ravageur des cultures à l'île de la Réunion. Proc. of Caribbean Meetings in Biological Control. 5-7 Nov. Guadeloupe, F.W.I., pp. 371-378.

WHITCOMB, W. B., T. D. GOWAN, AND W. F. BUREN. 1982. Predators of *Diaprepes abbreviatus* larvae. Florida Entomol. 65: 150-158.

WOLCOTT, G. N. 1955. Experiments with entomogenous fungi in Puerto Rico. Agric. Exp. Sta. Univ. Puerto Rico. Bull. 130.

WRIGHT, W. E. 1977. Insecticides for the control of dieldrin resistant banana weevil borer, *Cosmopolites sordidus* Germar. Australian Journal of Experimental Agriculture and Animal Husbandry. Melbourne 17: 499-504.

YU-CHEN, LI. 1964. Results of testing with *Beauveria bassiana* (Bals.) Vuill. against banana stem-borer weevil larvae. Plant Protection Bulletin (Taichung) 6(2): 121.